Astronomy 110G **Review Sheet for Exam #3**

The following summarizes the topics covered during the final third of the semester. The exam will be comprehensive, so review earlier materials (including review and sample question sheets).

Stars:

• Luminous properties of various types of stars are conveniently displayed in the Hertzsprung-Russell diagram. The main sequence is a mass sequence with high mass stars near the top left (high temperature, large luminosity) region. Giants, *etc.*, represent different and later stages in the lives of stars. HR diagrams for star clusters provide important clues to how stars form and evolve - and indicate the cluster ages.

• Residual heat, chemical reactions, gravitational contraction, nuclear fission, and nuclear fusion were considered as energy sources. Only the last can provide adequate energy output (L) over stellar lifetimes.

• Main sequence stars convert hydrogen to helium *via* the proton-proton (lower mass stars) or CNO cycle (higher mass stars) reactions. Either requires very high temperatures, reached only in the interiors (cores) of stars and during the star formation stage (if the pre-stellar gas cloud is massive enough). About 10% of the mass of a main sequence star is in the core where these reactions can occur.

• About 1% of the core mass can be converted to energy as hydrogen becomes helium. The Sun can "shine" for about 10 billion years before it exhausts the hydrogen in its core. (1% of 10% = 0.1% of the Sun's hydrogen mass being so converted.) Stars of sufficient mass can be (briefly) powered by other thermonuclear process (*e.g.*, helium and carbon "burning") during later (and briefer) evolutionary stages.

• Stellar evolution consists of a series of increasingly shorter cycles of contraction, heating, onset of nuclear reactions, a period of stability, and then fuel exhaustion. The number of cycles depends on the mass. Eventually a cycle is broken by a failure to heat adequately, or by collapse and a thermonuclear runaway. The result might be a gentle expulsion of the envelope of the star to form a planetary nebula, or a catastrophic supernova explosion. The latter occurs only for massive (more than 8 solar masses) stars.

• Stellar remnants are white dwarves, neutron stars, or black holes, depending upon how much mass is left behind. White dwarves are supported by their electrons being packed as closely together as possible and are about 100 times smaller than the Sun. Above about 1.44 solar masses gravity can "squeeze" the electrons into the protons to form neutrons. Resulting neutron stars (sometimes observed as pulsars) have neutrons packed as closely as possible, and are about 100,000 times smaller than the Sun. Above about 3 solar masses all remnants are black holes; even light cannot escape their strong surface gravity.

• Stellar remnants in some close binary systems can be detected *via* X-ray or γ-ray emission produced as matter from the companion star falls toward the remnant. The infalling gas is heated by compression.

• A "Type II" supernova occurs when a massive star dies. A "Type I" supernova occurs when a white dwarf is pushed over the "white dwarf limit" of 1.44 solar masses, usually by matter coming from a nearby expanding companion star. The energy released as the white dwarf collapses to a neutron star, and the interior helium, carbon or oxygen undergoes fusion, is probably enough to totally disrupt the star.

The Milky Way Galaxy:

• The "Milky Way" is just our galaxy viewed edge-on from our location inside it. The Galaxy contains stars, dust and gas, and, apparently, an admixture of "dark matter". Stars are often found in clusters. Tenuous gas or dust, which fills interstellar space, is also sometimes concentrated in bright or dark nebulae.

• Our view is constrained by the dust which dims and reddens starlight; we can't see far when looking in the plane. This is why Herschel's star counts mistakenly put the Sun in the center of things. The dust is more transparent at long (radio) wavelengths which permits us to map the gaseous component to large distances, usually using the radiation of cold hydrogen which emits and absorbs at a wavelength of 21 cm.

• Unlike other objects associated with our galaxy, globular clusters are seen all over the sky, concentrated somewhat toward the galaxy center. Few are seen near the plane because of interstellar absorption.

• Dust is strongly concentrated to the plane which is why the "spiral nebulae" (really other galaxies), and their elliptical galaxy counterparts, seem to avoid the Milky Way on the sky; they are present but obscured.

• Most of our galaxy's visible mass is in the flattened rotating disk which contains the younger stars, dust, and gas. Star formation is associated with spiral arms in this disk. The halo contains globular clusters (with the oldest stars) in a roughly spherical arrangement and with highly eccentric orbits about the center. The densest parts of the halo and the disk meet in the nucleus or bulge of our galaxy.

• The Sun lies about 8 kiloparsecs from its center and rotates about that center about once in 250 Myr. (at about 230 km/sec). Galactic mass interior to the Sun is therefore about 10 billion solar masses. The visible mass of the Galaxy, in stars (mostly), gas, and dust however, is very much smaller.

• Motions in the Galaxy indicate that most (90%)of its total mass is in the form of invisible "dark matter." It is not clear just what this is; dark stars, black holes, and exotic kinds of sub-nuclear particles are possibilities.

• The different ages, motions, and compositions in the disk, halo, and bulge can be explained in terms of Galaxy formation from a collapsing cloud in which star formation commences early - and is still ongoing. The accretion and merger of smaller galaxy-like structures is another formation mechanism for galaxies.

Other Galaxies:

• That the "spiral nebulae" might be galaxies (or "island universes") similar to our own was much debated. The question was resolved in the affirmative when Hubble obtained distances by observing individual stars (giants, particularly Cepheid variables, and supergiants) in nearby systems.

• The "spiral nebulae" are galaxies similar to our own. Spirals galaxies are are classified by appearance. Size of bulge, appearance of arms, bars, etc. (Sa, Sb, Sc, Sd,..; SBa, SBb, SBc, ..)

• Elliptical galaxies are largely dust-free, featureless, and (like the globular clusters) contain only old stars. Classified by apparent shape. (E0, E1, ...E7, with the last being the most elongated in appearance).

• The scenario of the formation of our galaxy (collapsing gas cloud eventually forming a rotating disk) might also apply to ellipticals if they are systems wherein star formation ended before a disk formed. An alternative hypothesis is that ellipticals are formed by the collision and merger of disk systems. Yet another hypothesis is that all systems, including disk systems, are formed by mergers of smaller systems.

• Irregular galaxies (Sm, Irr) such as the Magellanic clouds contain dust, gas, and young stars in a fairly disorganized fashion. They are flattened rotating systems but with large random disorganized motions.

• Lenticular galaxies (S0, SB0) seem intermediate between spirals and ellipticals. They have rotating disks, bulges, and halos, but don't show spiral structures, dust, or young stars. Some are barred.

• Some galaxies exhibit strong bursts of star formation or other violent events, usually in the nuclear regions. Quasars, extremely luminous active systems, are probably fueled by matter falling into massive black holes. This activity is often associated with strong radio, X-ray, and even γ-ray emission.

• Masses and dimensions of galaxies can be obtained from observed rotations (disks) or other internal motions (ellipticals) and their apparent sizes if the distance is known. In most instances, most of a galaxy's mass seems to be invisible; this is the case for our Galaxy. (The "dark matter" problem, again.)

• Distances to galaxies are determined by observing the brightest stars (supergiants and supernovae), the brightnesses and sizes of nebulae and globular star clusters, the size and brightness of the entire galaxy, or the properties of the brightest galaxies in clusters. Supernovae (to about 200 Mpc) are the best long distance internal indicators. Brightest cluster members can be used as indicators to perhaps 1,000 Mpc.

Cosmology:

• The Hubble Diagram shows that galaxies appear to be receding from us with a speed <u>v</u> proportional to distance <u>d</u>: v = **H**d, where **H** is the <u>Hubble Constant</u>. The relation is the same in all directions.

• This indicates that our universe is expanding, with the expansion having begun less than 20 billion years ago (if **H** > 50 km/s/Mpc). The present age of the universe is believed to be just under 14 billion years.

• The expansion of the universe is, in fact, a prediction of the General Theory of Relativity, Einstein's theory of gravity. (General Relativity, like Special Relativity, has "passed" all the experimental tests to which it has been subjected. These involve things like the rate of passage of time, the bending of light by gravity, light gaining or losing energy as it falls or rises in a gravitational field, etc. Where the predictions of Einstein's and Newton's theories have been in conflict, the former have prevailed.)

• The radiation from the "big bang" is seen today as the "cosmic background radiation" which peaks at microwave frequencies. This is 10,000°K radiation "cooled" to about 3°K by the redshift associated with the universe's expansion. It has the predicted uniformity and spectrum to a high degree of accuracy.

• Only isotopes of hydrogen and helium (plus a tad of lithium) were formed in the big bang; heavier elements were manufactured later by thermonuclear processes within stars. (By the time helium was made the universe had cooled too much for the reactions making heavier elements from helium to occur.)

• Present-day abundances of the light elements are close to those predicted in the big bang scenario.

• Whether the universe will continue to expand forever, or come to a halt and then collapse, depends partly upon the density of matter. It is the resulting gravity which acts to slow, and perhaps reverse, the expansion. The observed ("seen") density of matter is much less than the critical density, and the problematic "dark matter" isn't enough to make up the difference. Is the universe "open" or "closed"?

• The past history of the universe, including the rate at which its expansion has been speeding up or slowing down, can be viewed directly. The universe of objects observed at a distance of a billion light-years is the universe of a billion years ago!

• The basic "big bang" scenario explains most of what we see, and makes a number of testable predictions, but does not explain everything. It doesn't explain the amazing smoothness and uniformity we see or the closeness of the observed matter density to the critical density. Some of these can perhaps be explained by the "inflationary" scenarios describing the pre "big bang" expansion.

• Recent observations indicate the presence of a pressure-like component of empty space which is presently acting to increase the expansion rate. This mysterious component resembles the cosmological constant first "mistakenly" introduced by Einstein to prevent the expansion of his cosmological models.

• Current major problems and questions of cosmology center on properties of this cosmological pressure term ("dark energy") and upon the nature of the enigmatic "dark matter". Our universe is almost certainly

"open", its expansion will continue forever, and that expansion is probably accelerating.
Examination #3 - Review Questions:

What causes stars during formation (the pre-main sequence stage) to heat up enough for nuclear reactions to begin? Why do the nuclear processes require high temperatures anyway?

About what fraction of a star's mass of hydrogen gets converted to helium or heavier elements during its lifetime? Why is only this "core fraction" involved? What fraction of that hydrogen is converted to energy?

Stars are believed to form by the contraction of interstellar dust and gas clouds. What observational evidence supports this belief? (Where would you look for newborn stars - or those in the process?)

In what respects are the nuclear process powering upper and lower main sequence stars different? In what respects are they the same? From which of these two process does the Sun derive its energy? Why?

What effect does interstellar dust have upon a star's spectrum, color, and the determination of its distance? How can we tell if a star is suffering such effects? How does this affect our view of the Milky Way galaxy? (Remember Herschel's star-counting?)

How do we know that there is interstellar gas as well as dust? What is its effect on starlight? Can we observe the cold neutral hydrogen component? How?

Why would we expect white dwarf stars to be much more common than either neutron stars or black holes among stellar corpses? Why do we see so few of any of these?

Draw a Hertzsprung-Russell diagram and label its axes. Indicate where you would find (a) stars converting hydrogen to helium, (b) stars which have yet to begin hydrogen "burning", (c) stars which have recently exhausted their core hydrogen, (d) stars which have exhausted all nuclear energy sources, (e) the Sun.

What is believed to be the process which leads to the explosion of ordinary novae and some types of supernovae? What (different process) causes supernova explosions in massive single stars? How do you get supernovae from white dwarfs? (A hint is contained in the questions.)

What processes give rise to the so-called planetary nebulae? What do they look like, and what makes them glow? What kinds of stars are involved in this process? (Also, what does a supernova remnant look like?)

What principally determines whether a star winds up as a white dwarf, neutron star, or black hole? Why?

How does a star's mass affect its evolution and its location in the Hertzsprung-Russell diagram? What do observations tell us about the mass range for stars and the relative numbers of stars of various masses?

Explain how one determines the age of a star cluster from its Hertzsprung-Russell diagram. What other factors might indicate age differences? How do typical galactic and globular clusters differ in this respect? In what other respects (e.g., location) do they differ?

Make a sketch of our Galaxy providing face-on and edge-on views and some indication of size. What kind of a galaxy is it? Label major features and indicate where you would most likely to find (a) the Sun, (b) a globular cluster, (c) interstellar gas, (d) interstellar dust, (e) a main-sequence O-star and (f) the oldest stars.

How do the major components of our galaxy differ in regard to their locations? their motions? their ages? their chemical (elemental) compositions?

How do we use the rotation of the galaxy to map out the distribution of neutral hydrogen? Upon what optical phenomenon does this technique depend? (How do we tell where the emission is coming from?)

Radio astronomy has provided a particularly powerful tool for understanding the internal structure of our own galaxy, particularly the disk. Why is this? (See previous question!)
Explain how one determines the distance to a globular cluster. Then explain how these distances are used to locate the galactic center and determine our distance from it. About what is that distance?

The distances of the “spiral nebulae” were once controversial. What evidence suggested that they were other galaxies or “island universes” like the Milky Way? What suggested otherwise? What observations showed conclusively that they were extragalactic objects? (The last is the most important part.)

How does one determine the mass of a galaxy? (There are several possible ways). How do these determinations give rise to the belief that some galaxies (including our own) contain “dark” matter?

Much of the matter in our galaxy does seem to be “dark.” Evidence for dark matter is also found in clusters of galaxies. What is the evidence in for its presence in clusters? In what forms might this dark matter occur?

Describe as many methods as you can think of for determining distances to other galaxies. What assumptions and observations are needed to apply them? What are the limitations of these methods?

According to the Hubble classification, what are the basic types of galaxies? How do these types differ in appearance and the motions and properties of the stars, gas, and dust of which they are composed?

Among peculiar galaxies, the quasars are apparently the most energetic. On what basis do we believe that these are the most luminous of objects? What process is believed to account for their energy output?

Hubble discovered a relationship between observed radial velocity and distance for other galaxies. Describe this relation and how he obtained it. What is the significance of the “Hubble Law” insofar as the history of our universe is concerned?

That all galaxies seem to be moving away from us does NOT mean that we are in any sort of a “special” place or are particularly repulsive. The particular form of the Hubble expansion law indicates that no place in the universe is particularly “special”. Explain. (Hint: What does “linear” mean?)

Cosmologists are very interested in determining the present-day density of matter in the universe. (Hence the great concern over “dark matter”). Why do they care? More politely, what does the density of matter have to do with the history and future of the universe?

How can one use observations of distant galaxies to determine how much the Hubble expansion has been slowing down. Why do we expect it to be slowing down anyway? Is it? (See next question.)

The “cosmological constant” represents a pressure-like term which can cause accelerating expansion. Recent observations suggest that such an effect might actually be present. What observations?

What characteristics of clusters of galaxies provide some means of determining their distances? their masses? What assumptions about cluster galaxies are necessary for these determinations?

The “Big Bang” theory makes certain rather specific predictions about what we should see when we examine our universe. What are some of these predictions, and what is the status of their observational verification?

The only elements produced in significant amounts by the cosmological “Big Bang” are hydrogen, helium, and a bit of lithium. Why? If so, where did the heavier elements come from? What about the very heaviest elements, those whose atoms are more massive than iron?

What is the origin of the 3°K cosmic background radiation? Why is it so “cold”? At what wavelengths is it brightest?

What, approximately, is believed to be the current age of our universe? How does this compare to the age of the oldest stars in our Galaxy? The Earth? The span of human history? Give rough numbers for each.